Terminology for geomorphic units and habitats along the tropical coast of Western Australia

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Abstract

The tropical coast of Western Australia comprises a large range of shoreline types and coastal features that require categorisation, and this paper provides a nomenclature system to describe the geomorphic units and habitats of this region. A review of international and local literature concludes firstly that, at the regional scale, classifications tend to be too genetic to be of use in studies of the tropical Western Australian coastline, and secondly, that few studies have come to terms with either a nomenclature or philosophy of approach that deals with the various scales of coastal features.

This paper provides an approach to describing coastal features by utilising a nominated, fixed scale as a framework to nomenclature, and also provides a terminology by defining terms for the various scales of coastal features. The frames of reference in decreasing scale are defined as: regional scale, large scale, medium scale, small scale and fine scale. Within each frame of reference there are a variety of geomorphic units that are distinguished on criteria of depositional/erosional setting, geometry, morphology of surface, substrate, land surface position and geomorphic processes at surface. Coastal landforms thus can be systematically described in progressively decreasing scales, and a coastal type may be classified as a geomorphic unit at a fixed, nominated scale. The regional to fine scales of geomorphic units also may be used as a framework to distinguish types of habitats for organisms along a coast.

Introduction

Coastal environments have been studied by numerous authors in a wide range of scientific disciplines. As a result there is much literature dealing with classification, nomenclature, processes, products and principles appropriate to the scale and type of study be it biologic, sedimentologic, geomorphic, etc. Summaries of such studies are presented in texts by Cotton (1952), Valentin (1952), Davies (1964, 1980), Holmes (1965), King (1972), Bird (1976a), Chapman (1976), Bloom (1965, 1978), and Davis (1978). Other examples of specific studies in various disciplines of geology, sedimentology and biology are covered in Dyer (1973), Ginsberg (1975), Bird (1976b), Chapman (1976), Langford-Smith and Thom (1969), Day (1981), Stephenson and Stephenson (1972), and Wolff (1983).

In general, because studies are specifically oriented towards

(1) a given discipline, or

(2) a particular scale of reference, or

(3) a classification objective,

there has developed a diverse range of classification and nomenclatural systems which are only partly applicable or useful to all aspects of coastal science. For example, the classification of regional tectonic and morphologic coastal features by Inman and Nordstrom (1971) is at an inappropriate scale and emphasises factors largely irrelevant to the biologist who requires a classification of small to medium scale features, a scale at which biota and habitats develop and interact. Conversely, the small-scale differentiation of sediment units or habitat units as described in Cooper (1958), Ginsberg (1975), and Goldsmith *et al.* (1977) is inappropriate (i.e. far too detailed) for a study of regional classification as required by Jennings and Bird (1967).

The northwest coastline of tropical Western Australia, north of Pt Cloates through to Cambridge Gulf, comprises a large range of shoreline types and coastal features that require categorisation so that a consistent multidisciplinary terminology can be applied. In order to avoid problems that have developed with other classification systems, it is proposed here that a more rational conceptual framework and terminology be adopted in studies of coastal geomorphology and habitats in tropical Western Australia as a prelude to further work on geomorphology, sedimentology, stratigraphy, hydrology, oceanography, chemistry and biology in this region. The need for codification of terminology is necessary because of the amount of research on geomorphic units and habitats intended along the Western Australian coast as a whole, and because there already has been an inconsistent use of terms and concepts applied to geomorphic/habitat units.

The aim of this paper therefore is to provide a nomenclature system to describe geomorphic units and habitats of the tropical coast of Western Australia. However, prior to developing a nomenclature system, a review of global and local literature is presented so that the precedence of other workers can be assessed. In detail, the paper thus provides:

(1) a review of international and local literature on coastal geomorphology,

(2) an approach to describing coastal features for tropical Western Australia utilising a nominated *scale* as a framework to nomenclature, and

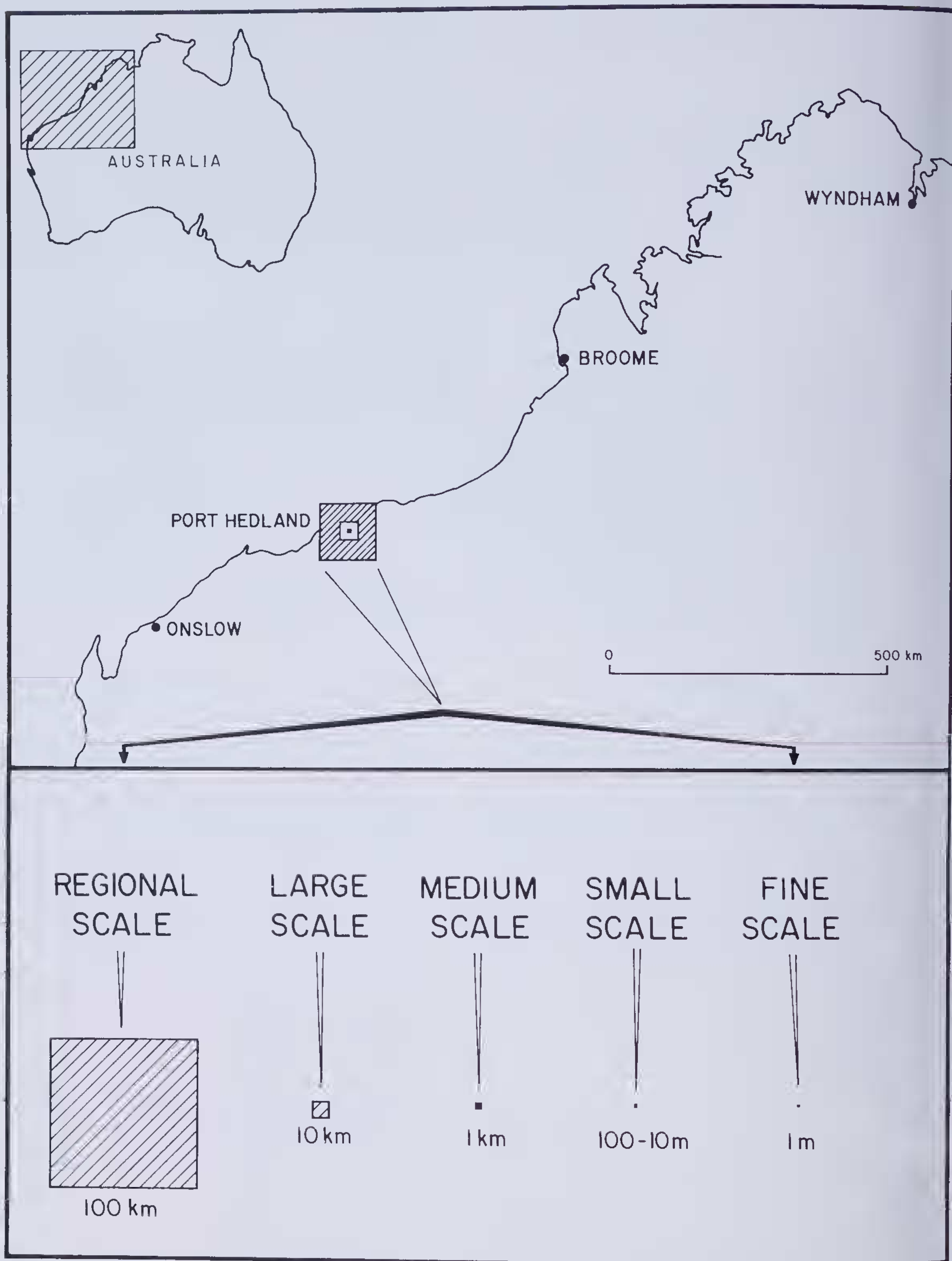

Figure 1.—Location of study area between Exmouth Gulf and Cambridge Gulf. The lower part of the figure illustrates the scalar frames of reference. In each case here the lower limit of scale is used in the frame.

(3) a terminology, by defining terms for the various scales of coastal features.

Much of the philosophy and description presented in this paper is scattered in various texts and scientific journals. However, in most cases the published works only deal with aspects of the approach presented here, or present the end products of classification (i.e. terminology) rather than a philosophy of approach to geomorphology which can be applied explicitly to more than one discipline.

The term coast as used here is intended to encompass the shoreline interface between land and sea as well as those features immediately landward of the shore. The term 'coastline' thus encompasses the tidal zone and the adjacent subaerial (supratidal) strip.

Methods

The primary method used to obtain information for this paper has been fieldwork. Some 12 months over the past 10 years have been spent in the field in a wide variety of coastal settings along the north-west and north coast of Western Australia (Fig. 1). Fieldwork has involved: mapping terrain and coastal features onto aerial photographs; documenting geometry of terrain/habitat units, including their surfaces, substrates and interfaces; and collecting substrate/soil and water samples. The remainder of the coast was surveyed and photographed during low-level flight by light plane and helicopter. Fieldwork was supplemented by examining the aerial photographs of coastal sections not amenable to access.

Global Review

Numerous classification schemes and their accompanying terminology have been established worldwide for natural coastal units. It is worthwhile to review some of these as a basis for precedence in either nomenclature or philosophy of approach for the Western Australian coastline.

General Classifications

Regional classifications presented hy authors in coastal geomorphology tend to be genetic, at least at the higher levels of heirarchial organisation (see Johnson 1919; Cotton 1942, 1952; Valentin 1952; Price 1955; Shepard 1963; Davies 1964; Bloom 1965). While this approach is appropriate to understanding the origins of coasts and assessing different factors that lead to coastal variability, it is not altogether useful for coastal workers who require a descriptive framework for their studies. Furthermore, much of these classification systems are concerned with regional scale or large scale features. They do not deal with the smaller scale divisions necessary for biologists, sedimentologists and (process-oriented) geomorphologists. Finally, and most importantly, classification must build on a foundation of descriptive studies and not *vice versa* (see Russell 1967). There are numerous instances of genetic classification systems that do not predict and therefore do not allow for some specific coastal categories. In practical terms, classifications should he constructed with the hindsight of available information. For these reasons the classifications described in the works cited above are considered inappropriate to this study.

Smaller-scale Subdivisions

Even though the established genetic classification of coastal landforms is rejected here as a basis for catergorising the coastline of tropical north-west and north Australia, the philosophy of approach that has evolved for smaller-scale coastal subdivision, the criteria for smaller-scale subdivision and the terminology that have been developed worldwide have some applicahility. However many of the criteria of classification and the resultant terminology are specifically oriented towards particular coastal systems and are not applicable universally; for example, the classification criteria and terminology of units within a delta obviously are not applicable to units of barrier dunes.

The principle of subdivision into units also is utilised in many different coastal settings and in different disciplines. The work of Zenkovitch (1967) is a useful example of this principle. Zenkovitch (1967) provides a descriptive approach, as well as a suite of terms, in classifying various types of sedimentary deposits along steep indented shorelines. For the classification Zenkovitch (1967) utilised primary non-gentic criteria of morphology (slope, orientation, position, secondary shape features, and quantification of some parameters), but also utilised dynamics and genetics. The classification incorporates many scales of reference; it allows description of coastal forms in detail, and also provides information and insight into processes of evolution and maintenance. The approach of Zenkovitch (1967) is a good example of coastal description and classification that should be emulated.

Similar internal classification of specific coastal landforms has heen accomplished in delta areas, coastal dune systems and barrier island/protected tidal flat systems (Cooper 1958, Allen 1970, Coleman *et al.* 1970, Gould 1970, Purser and Evans 1973, Coleman and Wright 1975, Evans *et al.* 1977, Goldsmith *et al.* 1977, Goldsmith 1978, McKee 1979). In delta areas for instance, depending on the need for detailed subdivision, authors have identified finer scale units using various criteria relevant for their explicit purpose: the Mississippi delta has been subdivided into numerous geomorphic/sedimentologic units as a framework to sedimentologic-stratigraphic studies (Fisk *et al.* 1954, Fisk 1961, Frazier 1967, Gould 1970); the Tabasco delta has been subdivided into geomorphic-stratigraphic units as a framework to biological studies (Thom 1967); barrier island coasts have heen subdivided into medium-scale units for the purposes of stratigraphic and biological studies (Hayes 1975, Phelger 1977) and small-scale units for purposes of sedimentologic studies (Hayes and Kana 1976). On the other hand geomorphologists in these areas have tended to recognise units for mapping purposes using mixed criteria, attempting to provide a geomorphic framework at various scales for studies such as surface processes, soils, vegetation and land use.

The scale at which a study is organised is determined by the type of detail required. Obviously detailed substrate morphology, which is of relevance to biologist or a sedimentologist, is largely irrelevant to a regional coastal geomorphologist who only needs to identify large-scale components. Conversely the scale at which a study terminates depends on whether there is a need for finer-scale information. The sedimentologist and biologist both can utilise geomorphic information at large scale (e.g. deltaic setting; cf. Wright 1978), medium scale (e.g. beaches/dunes within the deltaic setting) and small scale (e.g. dune crest, dune swale, back shore of the

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beach, and dune setting), but they also can utilise information at progressively smaller scales, and studies such as these then fall out of the realm of traditional geomorphology and into sedimentology *sensu stricto* (e.g. in further decreasing scale there are: large-scale bedform surfaces small-scale bedform surfaces, variability of grain size, variability of grain types).

On a worldwide basis, terminology appears to have followed the pattern listed below, even though the pattern has occurred fortuitously:

(1) Recognition of systems at the regional scale (the philosophy of this approach is covered by Mitchell (1973) and Bloom (1978) for terrestrial as well as coastal systems); usually a primary criterion utilised is whether the coastal units are depositional/erosional or submerged/emergent (Johnson 1919, Valentin 1962, Shepard 1963).

(2) Identification of coastal landforms (sediment bodies or erosional interfaces) based on their geometry, their phototone on aerial photographs, substrate type and biota (such as macrophytes).

(3) Further subdivision of the coastal system based on substrate differences, small-scale geometry, tidal levels and biota.

This pattern is one where the development of terminology and classification has been inadvertently scale-determined.

Discussion

The enormous wealth of terms that has been coined in geomorphic/sedimentologic studies of coastal areas is not altogether satisfactory for use in Western Australia. Certainly there are a sufficient number of relevant terms for large-scale geomorphic features such as deltas and ria coasts, but many terms for smaller scale features are non-existent in the literature or not applicable to the tropical coast of Western Australia. For instance, the classic, established system of geomorphic subdivision of a tidal flat (van Straaten 1954) envisages a high tidal flat, intertidal slope and subtidal zone. These units or their conceptual equivalent have been utilised subsequently by Thompson (1968), Allen (1970), and various workers in Ginsberg (1975). However, the units are not strictly relevant to the tidal coastline of north-west and north Australia. Similarly, terms to describe units peripheral to limestone barrier islands, rocky shores, ria shorelines are also inadequate. The literature, however, has provided useful terms for the following coastal settings, particularly at large and medium scales but less so for the small scale: (1) deltas, (2) beach/dune coastlines, (3) sandy barrier islands, and (4) spits/cheniers and tombolos (Frazier 1967, Morgan 1967, Zenkovitch 1967, Allen 1970, Coleman *et al.* 1975, Hayes 1975, Hayes and Kana 1976, Phleger 1977, Boothroyd 1978, Davis 1978, Wright 1978).

The main conclusion of this global literature review on coastal terminology is that, as scale of reference decreases and numbers of geomorphic units/entities increase, the terminology becomes less adequate or relevant to the study area of this paper. This is not surprising, since much of the tropical Western Australian coast is globally unique and it is to be expected that there may be undescribed combinations of geomorphic processes and landforms. Where globally established terminology is adequate or relevant to the north-west and north Australian coastline it is utilised later on in this paper.

Review of Literature on Central West/North-west/North Coastline of Western Australia

Introduction

A number of papers have already described segments of the central west, north-west and north Western Australian coastal and near-coastal (shallow-water marine) environments. Although not all of the studies are located in the tropical zone, it is worthwhile to review the main works here in order to appreciate what precedents in approach and nomenclature have been set. Specifically Jutson (1950), Fairbridge (1951), Russell and McIntyre (1966), Jennings and Bird (1967), Logan and Cebulski (1970), Jennings and Coventry (1973), Wright *et al.* (1973), Brown and Woods (1974), Hagen and Logan (1974), Read (1974), Jennings (1975), Thom *et al.* (1975), Woods and Brown (1975), Logan and Brown (1976), Davies (1977), Geological Survey of Western Australia (1980, 1982a, 1982b, 1982c), Semeniuk (1980, 1981a, 1981b, 1982, 1983, 1985), Galloway (1982), Johnson (1982), Semeniuk *et al.* (1982) and Hesp and Craig (1983) have published studies on geomorphology and sedimentology of the tropical Western Australian coast. In general the terminology, classifications and philosophy of these works follows that outlined in the Global Review.

General Studies

Many of the studies that deal with aspects of coastal geomorphology are concerned with regional scale aspects and so provide only a regional setting and listing of large-scale components (e.g. Jutson 1950, Fairbridge 1951, Jennings and Bird 1967, Geological Survey of Western Australia 1974, Davis 1977, Galloway 1982). Jennings and Bird (1967) for example, identify King Sound as a regional geomorphic unit, terming it an estuary, and do not proceed beyond identifying alluvial plains, tidal mud flats, mangroves and shoals. Publications by the Geological Survey of Western Australia (1980, 1982a, 1982b, 1982c) similarly only generally identify broad components of the shoreline and coast (e.g. mud flats, sand dunes, limestone reefs/cliffs/outcrops, etc.). Galloway (1982) provides a broad description of the coastal lands of North-Western Australia as part of a regional description of physiographic patterns associated with mangroves. Wright *et al.* (1973) similarly categorise the north-west coast of Australia into distinct provinces between the east Kimberley and Darwin. Davies (1977) provides a concise chapter on the whole Australian coastline and identifies regional components such as rocky coasts, tidal plain coasts, barrier island coasts, and relates these to the major influences of geological structure and large-scale processes. While relevant to an understanding of the main factors that develop different coastal types at regional and larger scales, these approaches of Davies (1977) and Wright *et al.* (1973) are largely inapplicable to studies at a more detailed level, or to studies that require a descriptive framework.

On the other hand some studies are only reconnaisance. Russell and McIntyre (1966) in a brief Australia-wide study describe a variety of tidal flats in tropical Western Australia. Although the various tidal zones are not allocated precise terms, the local study areas of these authors were described in some detail along selected transects. Hesp and Craig (1983) mention coastal landforms in a study of Pilbara coastal flora but provide a very incomplete picture of coastal geomorphology. Out of some 9-10 large- to medium-scale units obvious along the Pilbara coast, Hesp and Craig describe only three inter-related units and provide sketchy mention of the others.

Specific Studies

The remaining papers generally concentrate on coastal evolution, coastal sedimentology or marine habitats, and utilise geomorphic units as a framework to the specific studies. All these studies, however, are relevant to the philosophy of this paper because they employ geomorphic terms that extend from regional through to medium/small scale observations. These papers are reviewed below in terms of: the approach used by the author/s, the criteria utilised for subdivision of coastal units, and the terms used to name the subdivisions.

In a series of papers Logan and colleagues (*op. cit.*) describe the Shark Bay coastal and marine system, primarily from the point of view of carbonate sedimentology and evolution of stratigraphy. In general they have followed the global precedent: large-scale units were identified and later subdivided into smaller units as the studies required. The basic paper by Logan and Cebulski (1970) describes the large-scale geomorphic system as a framework for the sedimentology/stratigraphy of Shark Bay as: (1) Embayment Plains and Basins; (2) Sublittoral Platforms; (3) Sills: and (4) Intertidal-supratidal zone. There is further subdivision of these large-scale features into finer scale units based on substrate differences, tidal levels and slope (e.g. intertidal-supratidal zones are subdivided into rocky intertidal areas, intertidal beach areas and tidal-supratidal flats). Subsequent authors, e.g. Brown and Woods (1974) and Read (1974), have adopted the terminology/classification of Logan and Cebulski (1970), but modified and subdivided the units when necessary. Read (1974), working on seagrass platforms and sills, identifies smaller scale geomorphic entities of tidal channels, megaripples and sand ribbons as subsidiary elements of sills; Brown and Woods (1974), Hagan and Logan (1974) and Woods and Brown (1974) working on selected tidal flats of the region, subdivide the tidal-supratidal zone into six units based on substrates and levels above low tidal datum using terms such as beach ridges, supratidal flat and high intertidal flat.

Johnson (1982) in a sedimentology/stratigraphic study of the Gascoyne delta subdivided the deltaic system into a series of medium-scale geomorphic units termed bar unit, bank unit, strand plain unit (composed of beach ridges and tidal flats), channel unit, levee unit and flood plain unit. Smaller-scale geomorphic units within these geomorphic entities were noted in the description but not specifically nominated because the study endeavoured only to identify medium-scale units as a basis for stratigraphic studies.

Logan and Brown (1976) at Exmouth Gulf describe a regional framework for the coastal environment by delineating large-scale units termed geologic-physiographic provinces based on hinterland characteristics. Thereafter, at a smaller scale, they identify various terrain and tidal flat units. These units are described in detail and divided into a range of smaller scale units on the basis of substrate, creek incisions, fine-scale bedforms and biota. The units include types such as low-intertidal zone, mid-intertidal zone, supratidal zone, tidal creeks, beach ridges, etc.

In a study along another part of the Western Australian coast at Dampier Archipelago, Semeniuk *et al.* (1982) provide an heirarchial classification of a coastal zone as a framework for further studies on biology and sedimentology. At the largest scale four major marine settings were recognised: (1) Oceanic Zone, (2) Dampier Archipelago, (3) Nickol Bay Complex, and (4) Maitland Delta Complex. Thereafter the paper concentrates on the Dampier Archipelago and subdivides it into (geo)morphologic units such as submarine plains, islands, reefs and shoals, and (inter-related) channels, straits and embayments. These units are further subdivided into small-scale "geomorphic units" on the basis of geometry, substrate and tidal level, (e.g. intertidal beaches, intertidal flats, intertidal rocky shore, etc.). Since the primary objective of that paper was to describe the framework for biologic systems in the area, the next subdivision is termed a "habitat" and units such as intertidal flat are subdivided into a profusion of small-scale units useful for biologic purposes.

Jennings and Coventry (1973), Jennings (1975), and Thom *et al.* (1975) describe various geomorphic features in King Sound and Cambridge Gulf, respectively. Jennings and Coventry deal with the stratigraphic relationships and origin of small-scale spits and "barrier islands" along the eastern shore of King Sound. Jennings (1975) describes the stratigraphic relationship between Quaternary tidal flat deposits and red sand dunes; Jennings also presents several generalised geomorphic profiles across King Sound tidal flats within which are recognised three tidal-level zones and various tidal landforms such as sand shoals, cheniers, cliffs and lagoons. Thom *et al.* (1975) in a study of mangrove ecology in Cambridge Gulf similarly provide several generalised geomorphic profiles within which they identify three tidal-level zones as well as beach ridges and creeks.

In a series of papers on mangrove-lined tidal flats of northwestern Western Australia, Semeniuk (1980, 1981a, 1981b, 1982, 1983, 1984) provides a subdivision and classification scheme specifically of tidal zone systems. Probably the most relevant paper to this study is Semeniuk (1981b) wherein tidal zones are subdivided, described and mapped, and a classification of tidal flat types presented based on substrate, stratigraphy, suites of geomorphic units and inferred Holocene history. Generally in all the work by Semeniuk (*op cit.*), the approach adopted was: (1) identification of geometric forms on the tidal zone (e.g. ridges *vs* flats *vs* creeks), (2) recognition of slope (e.g. flats, slopes and cliffs), (3) identification of substrate types, and (4) identification of small-scale surface morphology (e.g. smooth surface such as salt flat *vs* hummocky burrow-mounded surface such as mangal flat). In this manner tidal flats were subdivided into salt flat, mangal flat, low tidal flat, sand flat, shoals, alluvial fans.

Discussion

There are several main conclusions that can be drawn from the literature on the central west, northwest and north coast of Western Australia. Firstly it is obvious that there has been a predominance of studies on depositional areas such as tidal flats and deltas, and few—if any—on the other diverse geomorphic entities such as barrier islands, rocky shores, beach/dune shores etc. Overall, the works on Shark Bay, Dampier Archipelago and tidal flats generally, serve to show that the heirarchial system of classification employed elsewhere in the world has been successfully applied in Western Australia though there is an inconsistency in terminology at the smaller scales, differing concepts of what constitutes the largest scale of reference in defining large-scale units, and some inconsistency in the use of criteria at all scales. For instance, the criteria on which large-scale units are recognised are: (1) regional geology and physiography of the hinterland (Logan and Brown, 1976); (2) geometry of coastal form (Semeniuk *et al.* 1982); (3) erosional *versus* depositional system (Davies 1977); (4) regional processes (Davies 1977).

The smaller scale units present yet another problem because they have been identified and subdivided *variously* on numerous criteria that include geometry, slope, level relative to MSL and substrate. Few studies have attempted to come to terms with either a nomenclature or a philosophy of approach that explicitly deals with the various scales of geomorphic units.

It is also obvious that since the various authors have worked in diverse coastal systems, terminology has evolved for specific areas. This terminology is not applicable throughout the region. For instance, consider the example of tidal flats (Brown and Woods 1974, Hagan and Logan 1974, Jennings 1975, Thom *et al.* 1975, and Semeniuk 1981b). These authors have used a wide variety of criteria to subdivided tidal flats and hence develop independent systems of terminology. Brown and Woods (1974), Hagan and Logan (1974), and Logan and Brown (1976) utilise tide levels; Jennings (1975), and Thom *et al.* (1975) utilise tidal levels, substrate and slope, while Semeniuk (1981b) employs criteria of tidal level, slope, shape, substrate and small-scale morphology.

A similar comparsion of terminology and criteria for subdivision for rocky shores (cf. Read 1974 and Semeniuk *et al.* 1982) also shows variability in approach and nomenclature. The same principle applies to other small-scale geomorphic units. In summary, it may be noted that authors tend to subdivide geomorphic entities in smaller units on whatever criteria are suitable or relevant to their particular study. These criteria of course are not consistent from discipline to discipline and consequently independent studies tend to result in a profusion of dissimilar terminology. There is therefore no single nomenclature system considered adequate for the whole region, but where established terminology is adequate or relevant to this paper, it is utilised later on. Overall, however, it seems preferable to develop a consistent and new approach and terminology for the coastline of this study area. The proposed approach and terminology are discussed below.

The Proposed Classification and Terminology: Use of Scale

The purpose of this section of the paper is to rationalise the terminology and classification of tropical Western Australian coasts with particular reference to scale. This is approached in two ways: firstly, by reviewing the use of the term "geomorphic unit" and secondly, by proposing scalar terms for description/nomenclature of various geomorphic features along the coast.

The Term "Geomorphic Unit"

One fundamental problem in many classification and terminology systems is the use of the term "geomorphic unit" or some other equivalent term such as "facet" (cf. Bourne 1931, Brink *et al.* 1965). Most authors appear to use these terms at one scale only; thereafter, when referring to smaller or larger scale units, terms such as "elements" or "system", respectively, are introduced. When detailed studies proceed beyond the currently defined scalar frames of reference, terms are borrowed from related disciplines (such as sedimentology). To illustrate this point of scale-determined nomenclature, an example is drawn from work on the Swan Coastal Plain. Although outside the study area of this paper it serves to show how the terms "geomorphic unit"/"geomorphic element" are utilised. The term "geomorphic unit" is used to refer to the Swan Coastal Plain itself and the term "geomorphic element" is then used to refer to units *within* the Swan coastal Plain (McArthur and Bettenay (1960) after Woolnough (1920). If workers require to subdivide the "geomorphic elements" into finer scale catergories such as ridges *versus* swales, on current practices there are presently no terms for the nomenclature for the smaller scale categories. This pattern of introducing new category terms for landform entities at each scale of reference is discussed in Brink *et al.* (1965), Perrin and Mitchell (1969) and Mabbutt (1968), and is a result of geomorphologists attempting to develop both a philosophy of approach and terminology concurrent with genetic classification. In practical terms, however, neither geomorphic units nor the aggregations (suites) of such units conform to any established size classes.

Semeniuk *et al.* (1982) confronted similar problems in the Dampier Archipelago. Once the term geomorphic unit was allocated to features at a particular scale, then by principle of exclusion larger and smaller scale features could no longer be termed "geomorphic units". Semeniuk *et al.* (1982) then referred to larger scale units as "morphologic units" and smaller scale units as "habitats". In reality all are geomorphic units for their nominated scale. Semeniuk (1985) partly resolved this problem of geomorphic unit nomenclature by introducing scale terms to qualify the term "coastal features". Thus large-scale coastal (=geomorphic) features, medium-scale coastal (=geomorphic) features, and small-scale coastal features were described.

If the use of the term "geomorphic unit" appears to be an obstacle to scalar classification and terminology then perhaps a discussion is required to determine if the term itself is a problem. The "geomorphic" component of the term refers to landform shape, and as such its meaning is reasonably explicit. A "unit" may be defind as the smallest entity recognised *at a particular scale.* Sand grains are the units of a sand deposit at hand specimen scale, while embayments, inlets and rocky headlands are the units of a ria coast at the aerial survey scale. On this basis a geomorphic "unit" should be viewed as any recognisable or mappable landform entity within a nominated scale of reference. Ria coasts, deltas and rocky shores may be observable units at the regional scale while tidal flat subdivisions generally are not. However, the tidal flat subdivisions (units) become differentiated at the medium- and small-scale of observations. Thus, any landform within the various scales of reference may contain a set of observable units, and *all* of these should be termed "geomorphic units" as long as the scale of observation is nominated.

It is proposed therefore that the term geomorphic unit be retained throughout descriptions of terrain/coastal zones but that the *scale of reference be fixed and nominated*. This allows a worker to describe features of a land surface to a level as fine or as large as is desired.

This scalar approach is already utilised by oceanographers who refer to macro, meso and micro-scale oceanographic features; by geologists who utilise macro, meso and micro-structural features (Turner and Weiss 1963); and by climatologists (Barry 1970, Barret 1974). Each of these disciplines, however, has its own concepts and boundaries of scale to which they refer macro-, meso-, and micro-. A reconnaissance of many standard geomorphology texbooks, however, will find scalar terminology or its equivalent generally missing form their index and contents (text). (Bird 1976, Bloom 1978, Embleton *et al.* 1978, Davies 1980, Gardiner and Dackombe 1983, Gardner and Scoging 1983, Goudie 1981, King 1966, 1972, 1975, McCullagh 1978, Trewartha *et al.* 1968, and many others.) In contrast, where a scalar approach in terrain description is utilised by geomorphologists, the hierarchial classification (system, facet, element) is based on criteria of genetic relationships of landform units as well as scale (Linton 1951, Brink *et al.* 1965, Perrin and Mitchell 1969); *scale is not utilised in these studies as the sole framework.*

The Proposed Scale Terms

The terminology proposed for the various scales of features evident along the tropical Western Australian coastline is as follows (Fig. 1 and Table 1):

- Regional
- Large
- Medium
- Small
- Fine.

Table 1

Summary table of scale terms and their respective scales of reference

Scale terms	Frame of reference
Regional (Megascale) scale	500km x 500km to 100km x 100km
Large (Macroscale) scale	50km x 50km to 10km x 10km
Medium (Mesoscale) scale	5km x 5km to 1km x 1km
Small (Microscale) scale	500m x 500m to 10m x 10m
Fine (Leptoscale) scale	5m x 5m to 1m x 1m

Workers who prefer to use ancient Greek in the construction of terms may use Megascale, Macroscale, Mesoscale, Microscale and Leptoscale (see Liddell and Scott, 1925-1940 for definition of mega, macro, meso, micro, and lepto) as synonymous terms. A description, with examples, of these scalar frames of reference is presented below.

Regional scale (or Megascale): morphology evident or mappable at the scale of a region, i.e. within frames of reference of 500km x 500km down to 100km x 100km. This scale would incorporate the term "land region" by Linton (1951), Brink *et al.* (1965), and Perrin and Mitchell (1969), and would be termed "regional" by numerous other authors (e.g. Cooke and Warren 1973). The term "regional" as utilised here refers only to the particular size; other authors tend to use the term "regional" with genetic implication (e.g. Jennings and Mabbutt 1977, and Mabbutt 1968). Some examples of coastal types along the tropical Western Australian coastline within this scale of reference are: ria shores, delta lands, and beach/dune shores.

Large scale (or Macroscale): morphology evident or mappable at frames of reference of 50km x 50km down to 10km x 10km. This scale would incorporate the term "land facet" by Linton (1951), Brink *et al.* (1965), and Perrin and Mitchell (1969), and perhaps would be termed "basin scale" by Cooke and Warren (1973). Examples within a ria coastal setting in northwestern Australia are (after Semeniuk 1985): riverine channels, narrow embayments, broad embayments, cliff/rocky shores, sandy shores, islands, and subtidal reaches or waterways.

Medium scale (or Mesoscale): morphology evident or mappable at frames of reference of 5km x 5km down to 1km x 1km. This scale would incorporate the term "site" by Linton (1951), "land element" by Brink *et al.* (1965) and Perrin and Mitchell (1969). Examples within broad embayments of a ria coastal setting are (after Semeniuk 1985): spits, cheniers, rocky headlands, tidal flats, tidal creeks and alluvial fans.

Small scale (or Microscale): morphology evident or mappable at frames of reference of 500m x 500m down to 10m x 10m. This scale would still incorporate the terms "site" and "land element" by Linton (1951), Brink *et al.* (1965), and Perrin and Mitchell (1969), and would be termed "local scale" by Cooke and Warren (1973). Examples on tidal flats in northwestern Australia are: a smooth salt-encrusted mud surface (= salt flat); a smooth rippled sand surface (= sand flat); and a hummocky, burrow-mounded mud surface (= mangal flat).

Fine scale (or Leptoscale): morphology evident or mappable at frames of reference of 5m x 5m down to 1m x 1m. This scale would incorporate the term "microrelief" by Hunt (1972), and "microform" by Tricart (1972). Examples on tidal flats in northwestern Australia include ripple marks, erosional rills and burrow mounds.

For purposes of this paper there is no need to proceed beyond the fine scale. If frames of reference smaller than "fine scale" were to be utilised then the observations would be out of the realm of traditional geomorphology; thus fine-scale represents the lower scalar limit of the science of geomorphology in this paper.

At the other extreme, there are of course frames of reference that extend beyond "regional scale"; however, in tropical Western Australia the next scale-unit above regional scale (i.e. 1 000 km x 1 000 km) is subcontinental and would incorporate the entire study area within which units such as Pilbara coastline Canning Basin coastline and Kimberley coastline would be the primary components. At the subcontinental scale geological features such as cratons, blocks and basins exert a major influence on coastal form, and therefore perhaps the nomenclature of larger scale systems should follow geological subdivision based on tectonic/structural/lithologic criteria, a conclusion also reached by Davies (1977).

It should be noted that the nominated scales may be applicable only to the northwest and north tropical coast of Western Australia. Elsewhere coastal features may be of a different magnitude of size-variation, and a redefinition of absolute values of regional-, large-, medium- and small-scale may be necessary.

Landforms thus may be described in progressively decreasing scales, and a coastal type can be classified as a geomorphic unit at a particular nominated scale (e.g. a sand flat on a tidal zone is a small-scale geomorphic unit, a tidal flat can be a medium-scale geomorphic unit, while the deltaic complex to which they belong may be a regional scale geomorphic unit (Fig. 2).

The Proposed Classification: Use of Geomorphologic Terms

The purpose of this section of the paper is to identify and describe various geomorphic units along the coast of tropical Western Australia within the five defined scales of reference.

Criteria

Numerous criteria can be used to identify geomorphic units (see literature reviews) and these criteria are applicable at all scales:

- depositional *versus* erosional system (in a long-term Quaternary geological context)

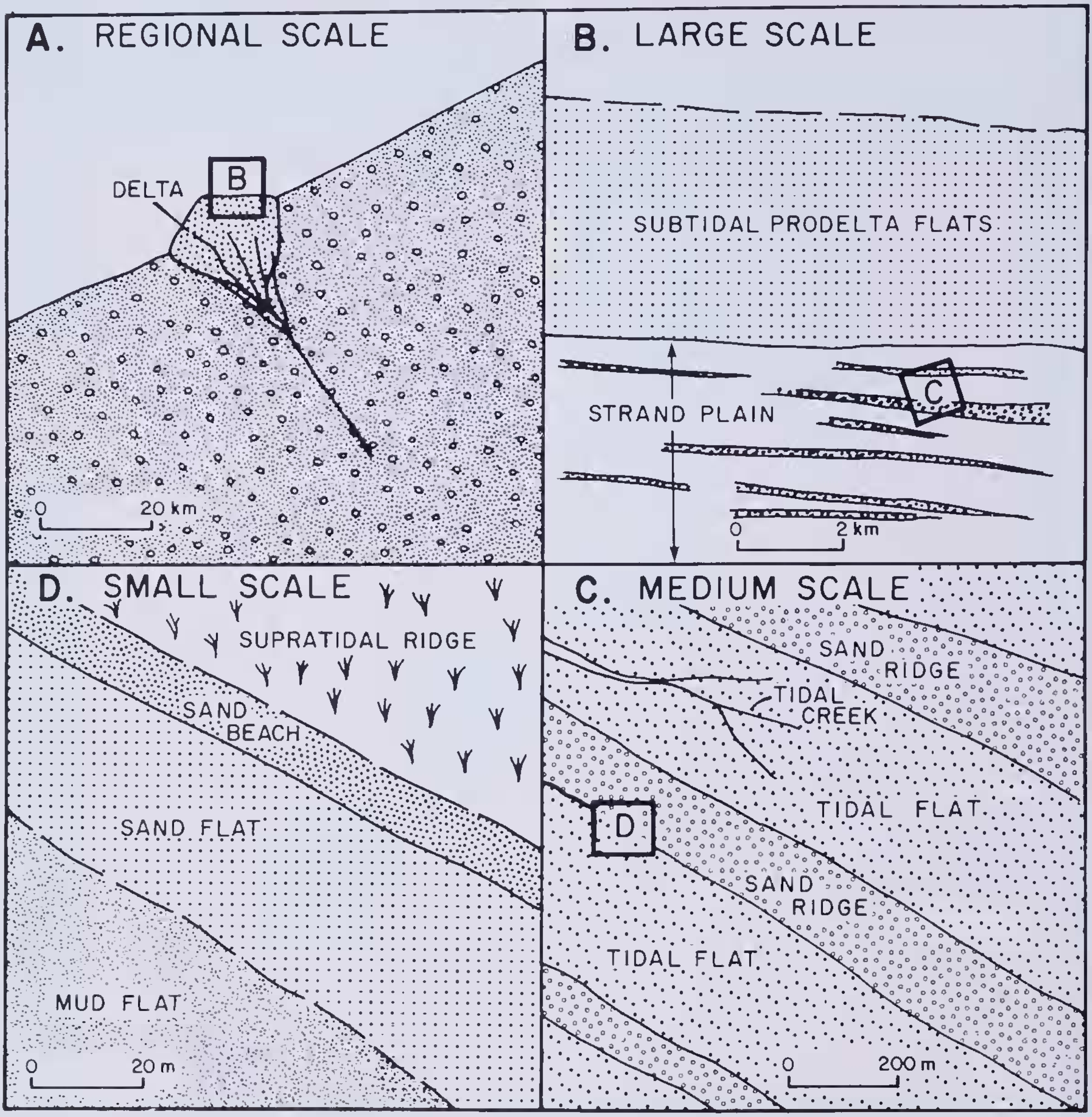

Figure 2.—The various geomorphic units in a deltaic setting observable and mappable at 4 scales of reference.

- geometry of landform (plan geometry, slope, relief)
- morphologic features of surface, at various scales
- substrate types, which can influence the development of surface morphology at all scales
- dominant (geomorphic) processes at surface, which also influence development of various morphologic features
- landsurface position, that is location within a coastal system (e.g. interface between hinterland and tidal flat).

Many of these criteria already carry an implication of variability of landforms: for instance, the fact that a coastline is constructional (e.g. a delta) implies there are a wide range of medium- and small-scale associated geomorphic features (such as sand spits, channels and flats) that are extremely different to those developed along an eroding shoreline (e.g. cliff and bouldery shores). Some of the above criteria also encompass the genetic classifications/implications of other authors. For instance, a marine-inundated fluvially-dissected coastal terrain, which is termed a ria, may be a primary criterion for some authors (Johnson 1919, Shepard 1963), but it may have been used with genetic implication; the criterion 'geometry of landform' proposed here, however, is non-genetic, but it will still serve to distinguish these types of shorelines (rias) from other shore types.

Geomorphic Units of The Tropical Western Australian Coast

There is a limited range of geomorphic units that occurs within each of the scales of reference nominated above, and each scale of reference tends to have a very distinct suite of units, especially at the smaller scale. The geomorphic entities in north-west and north Australia that are evident within the five scales nominated above are listed below and are described in Tables 2-5, and maps are presented in Figs. 3-7. This list is by no means complete, especially at the smaller scales, and further work may refine, or add to the terminology. It should also be noted that *some geomorphic units can make an appearance at a number of different scales*, because of the size variation of such units. Salt flats in high tidal zones exemplify this; they are evident at regional scale (King Sound), as well as large scale through to small scale, where they can be merely small patches 25m² in size.

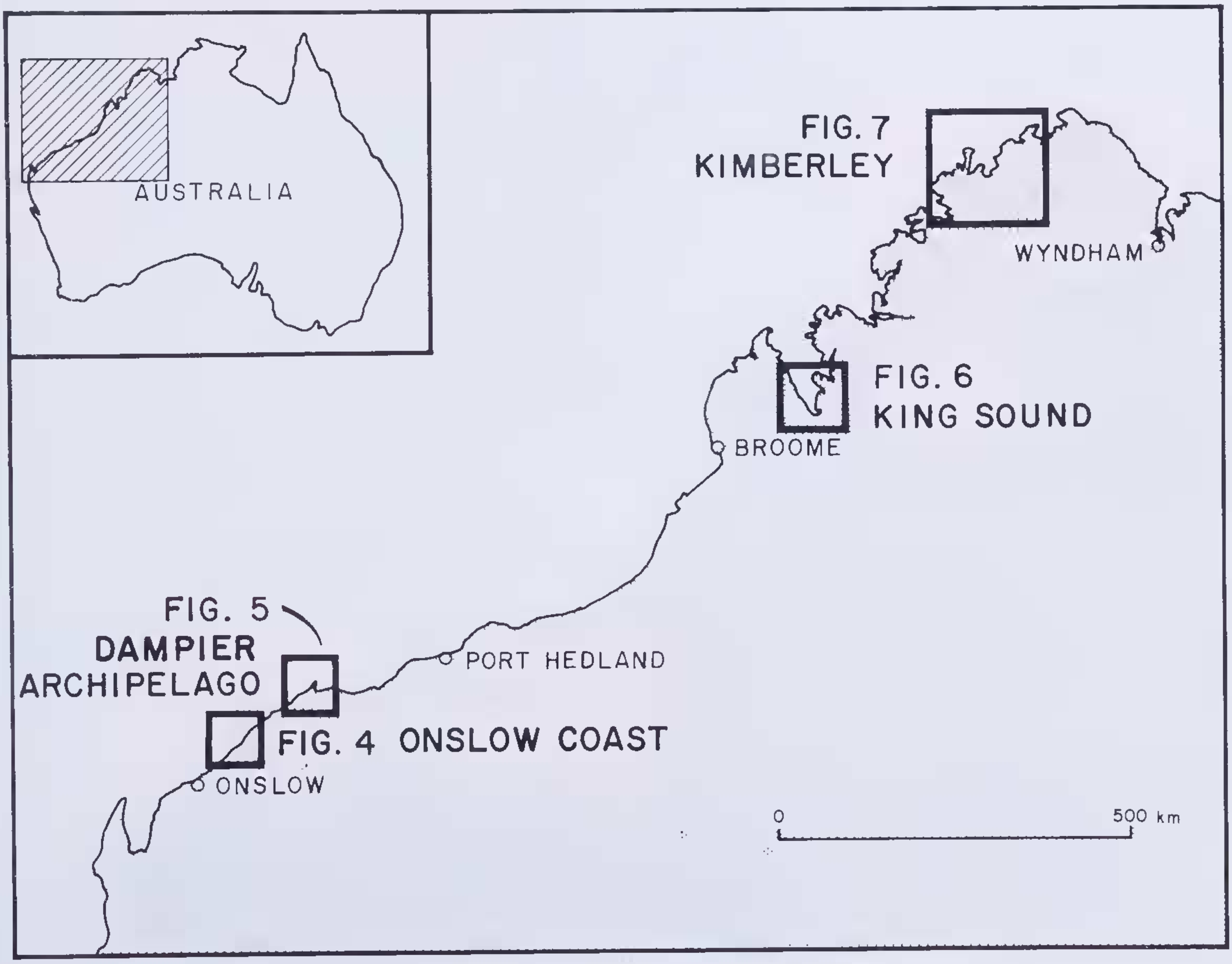

Figure 3.—Map showing study area and location of detailed sites illustrated in Figs 4-7.

Many of the terms utilised herein have been obtained from the global and local literature and are cited accordingly. However, for some of the (progressively) smaller scale units new terminology has been developed in this paper. The use of some established terms sometimes are used differently to some authors working in different environments (e.g. the term 'beach ridge'). Nonetheless, the definitions of the terms as used in this paper are presented in Tables 2-5. Readers familiar with studies in sedimentology will realise that at many scales terminology in geomorphology and sedimentology is synonymous. Both disciplines essentially deal with surface morphology and consequently they describe the same features.

Table 2

Regional-scale Geomorphic Units

Unit	Description	Examples
Archipelago	Group of islands; grades into ria shore	Dampier Archipelago
Barrier island complex	Narrow, shore-parallel limestone barrier ridges which bar and protect inlets, lagoons and tidal embayments	Port Hedland coastline
Beach/dune shore	Strip of shore parallel coastal dunes with shoreline beach, beach ridges and foredune	Eighty Mile Beach
Delta lands	Cuspate to deltoid lowlands at mouths of main rivers	De Grey River delta
Gulf complex	Large embayment or inlet penetrating deep into the mainland; grades into tidal embayment	Exmouth Gulf
Ria shore	System of bays and inlets of riverine origin cut into a rocky hinterland; grades into archipelago systems	Kimberley coastline
Rocky shore	Coast cut into a rocky hinterland but without marked development of inlets	Cape Range western shore
Tidal embayment (tidal land)	Extensive tidally-inundated embayment or inlet grades into gulf system	Roebuck Bay

Regional scale geomorphic units

Archipelago
Barrier island complex
Beach/dune shore
Delta lands
Gulf complex
Ria shore
Rocky shore
Tidal embayment

Some of these units are *intergradational:* ria shores and archipelagos; gulf complexes and tidal embayments; delta lands and barrier island complexes. Examples of these units are illustrated in figs. 3-7. Description and occurrence of the units are presented in Table 2.

Large scale geomorphic units

Alluvial fan
Barrier island
Beach/dune shore
Broad embayment
Cliff/rocky shore
Headland
Island
Narrow embayment
Riverine Channel
Shoals
Strand plain
Tidal creek
Tidal flat (and in many cases, types of tidal flat)

Some examples are illustrated in Figs 3-9. Description and occurrence of the units are presented in Table 3.

Table 3

Geomorphic Units at the Large-scale

Unit	Description	Selected examples
Alluvial fan	Fan to deltoid to elongate alluvial deposit	King Sound west shore; Pilbara coast between Onslow and Dampier
Barrier island	Narrow limestone or sand ridges which may be mantled by dunes, beach ridges, soils and tidal deposits; surrounded by water at high tide	Finucane Is.-Port Hedland area; Port Weld; north-east of Onslow
Beach/dune shore	Shore-parallel coastal dunes with accompanying beach ridges, foredune and shoreline beach	Eighty Mile Beach
Broad embayment	Broad inlet or embayment; with permanent water on all tidal levels; margins are tidally exposed	Kimberley coastline; see Fig. 7A, 7B
Cliff/rocky shore	Coast cut into rocky hinterland; may be composed of cliffs, or bouldery slopes, or benches, cliffs and pavements; may contain local pocket beaches	Cape Range western shore; Kimberley coastline
Headland	Rocky coast promontory which may be composed of cliffs, bouldery slopes, benches or pavements	Cape Range north tip
Island	Supratidal landforms surrounded by waterway or tidal lands	Cape Preston; West Intercourse Is., Dampier Archipelago
Narrow embayment	Narrow inlet, with permanent water on all tide levels; margins are tidally exposed	Kimberley coastline; see Fig. 7A, 7B
Riverine channel	Narrow channel system that is the seaward extension of riverine channels	Fortescue River; Turner River
Shoals	Hummocky, undulating, expansive sheets and mounds of sand	King Sound central embayment zone (Fig. 6A)
Strand plain	Lowland composed of linear beach ridges and dunes separated by intervening tidal lands	Turner River delta; De Grey River delta; Ashburton River delta
Tidal flat (tidal land)	Tidally-inundated lowland	West shore King Sound, see Fig. 6A; Dampier Creek, Broome
Tidal creek	Tidal-water drainage/channel system that typically incises tidal flats	King Sound, see Fig. 6A

Medium scale geomorphic units

This group can be recognised on criteria listed above. Location relative to MSL also is useful to note. The list includes:

- Alluvial fan
- Alluvial plain
- Barrier Island
- Beach
- Beach ridge
- Chenier
- Dunes[1]
- Fluvial channel
- Foredune
- Hinterland/tidal flat margin
- Lagoon
- Levee
- Nearshore bar system
- Rock island
- Rock pavement
- Rocky shore
- Sand island
- Shoals
- Spit
- Tidal Creek
- Tidal flat[2]

Some examples are illustrated in Figs 3-7 and Figs 9-10. Description and occurrence of the units are presented in Table 4.

Table 4

Medium-Scale Geomorphic Units

Unit	Description	Selected example
Alluvial fan	Fan to deltoid to elongate alluvial deposit	Fig. 10D
Alluvial plain	Ribbon to sheet alluvial deposit	not illustrated
Barrier island	Narrow limestone or sand ridge which may be mantled by dunes, beach ridges, soils and tidal deposits; surrounded by water at high tide	Fig. 4B
Beach	Intertidal slope of sand or gravel developed on a strip along the shore of dunes, beach ridges, spits, etc.	Fig. 10E Fig. 12D
Beach ridge	Shoestring sand (or gravel) deposit developed to supratidal level by storm activity: occurs to landward of beach slope	not illustrated
Chenier	Detached shoestring or bar sand deposit built to high tidal or supratidal levels surrounded by muddy tidal-lands; may be tidal to supratidal	Fig. 10B

[1]Types of dunes, such as transverse, parabolic, linear and barchan can also be differentiated.

[2]In many instances, types of tidal flats such as salt flats, mangal flats and low tidal flats are recognised, although the small distinguishing characteristics that comprise the phototone evident on an aerial photograph are not evident at this scale.

Table 4—continued

Medium-Scale Geomorphic Units

Dunes	Shoestring to lensoid to mound-like accumulations of sand of some relief developed along the coast by onshore aeolian activity; may be subdivided on external geometry and relation to wind direction (McKee, 1979) into *linear, parabolic, transverse* and *barchan* types; dunes may be mobile or immobile, and bare or vegetated (Also see foredune).	Fig. 8C
Fluvial channel	Channel system of rivers which meet the coast	Fig. 10D
Foredune	Shoestring deposit of sand developed by aeolian process usually as a low ridge immediately landward of the beach	not illustrated
Hinterland/ tidal flat margin	Complex system of interface between hinterland and tidal flats; may be narrow or broad; diffuse to sharp	Fig. 7C
Lagoons	Impounded depression or channel	not illustrated
Levee	Narrow channel-paralled mound or rise developed on bank of channels	not illustrated
Low tidal to near-shore bar system	System of low-relief bars and intervening troughs developed on low tidal to shallow subtidal zones	not illustrated
Rock island	Supratidal island of limestone or sandstone or Precambrian basement surrounded by waterways or tidal-land	Fig. 10B
Rock pavement	Extensive low-lying subhorizontal to gently-inclined pavement of rock (either limestone or sandstone or Precambrian basement)	Fig. 10 E
Rocky shore	Shoreline composed of cliffs, or steep slopes or bouldery deposits; locally-developed pocket beaches	Fig. 5B
Shoals	Hummocky to undulating sheets and mounds of sand	not illustrated
Sand island	Supratidal hummock of sand surrounded by tidal lands	Fig. 10A
Spit	Shoestring or bar sand deposit emanating from headland of rock or dune field; may be tidal to supratidal	Fig. 9B
Tidal creek	Meandering to bifurcating to ramifying drainage systems cut into tidal flats; may drain out on a low tide	Fig. 10F
Tidal flat (and, in many cases, types of tidal flats; see Table5)	Gently-inclined tidally-inundated lowlands	Fig. 10C

Table 5

Geomorphic Units at the Small Scale

Medium-scale geomorphic setting	Small-scale units	Description	Occurrence with respect to tidal level
Alluvial fan	channel	drainage/distributary incision	depending on region, all units may be located anywhere between levels LWN to supratidal
	lobes	progradational/accretionary lobate promontory at margins of fan	
	flat	relatively flat surface of alluvial fan	
Alluvial plain	channel	drainage/distributary incision	supratidal
	flat	relatively flat surface of alluvial plain	
Bar system	bars	low relief sand wave	low tidal to subtidal
	troughs	intervening swale between bars	
Beach	beach slope	intertidal slope of beach	intertidal: MLWS-MHWS
	backshore (= berm)	impermanent nearly horizontal or land sloping bench on backshore of a beach	storm water levels
Beach ridge	beach ridge crest	highest line or surface of a beach ridge	storm water-supratidal level
	beach ridge slope	flank of a beach ridge	high intertidal to suptratidal
	beach ridge swale	trough between any 2 successive beach ridges	
	hummock	irregular mound on surface	
Chenier	chenier crest	highest line or surface of a chenier	high intertidal-supratidal
	chenier slope	flank of a chenier	
	chenier lobe	accretionary lobate promontory at inner margin of chenier	
Dune	dune crest	highest line on surface of dune	all supratidal
	dune slope	flank of dune	
	dune swale	trough between any 2 successive dunes	
	dune hummock	low relief sand mound	
Foredune	foredune crest	highest line of surface of foredune	all supratidal
	foredune slope	flank of foredune	
	foredune hummock	low relief sand mound	
Fluvial channel	channel	water-filled or dry, relatively narrow erosional incision	all supratidal
	bars/shoals	moundlike sediment accumulations in mid-channel areas	
	banks	steep margin of channel	
Hinterland/tidal flat margin	gravel apron muddy sand to sand apron muddy sand to sand sheet	narrow ribbon of sedimentary material bordering a supratidal area of bedrock, or limestone, sand plain; slope generally steeper than adjoining tidal flat but less so than hinterland	generally high tidal-supratidal; in some cases mid-tidal to supratidal
	channels/gutters	erosional incisions	
Levees (fluvial)	crest	highest line or surface of levee	all supratidal
	slope	inclined surfaces of levees	
	gutters	erosional channels cut into levees	
Rock island	cliff	vertical/steep rocky surface	high intertidal to supratidal
	gravel/sand apron	ribbon deposit of gravel/sand flanking island	
	channels/gutters	erosion incisions	
	subaerial surface	the varied subaerial surface of an island	supratidal

Table 5—continued

Medium-scale geomorphic setting	Small-scale units	Description	Occurrence with respect to tidal level
Rocky shore	cliff shore	vertical/steep sheer surface	these units occur at various levels from supratidal, intertidal to subtidal
	fissured rocky shore	vertical/steep to inclined, guttered to cracked surface	
	gutter	erosional incision	
	pavement	flat to gently inclined surface	
	bench	narrow terrace	
	gravelly shore	gravel accumulation in sheet, ribbon or lens form	
	bouldery shore	boulder accumulation in sheet, ribbon or lens form	
	pocket beach	sand accumulation in lens or sheet form	
	reef	protruding knoll of rock	
Rock pavements	limestone pavement	flat to moderately inclined pavement of limestone	low tidal to supratidal
	rock pavement	flat to moderately inclined pavement of rock other than limestone, e.g. Precambrian rock	
	cliff	small cliffs usually 2m cut into the pavements	
	pool	depressions 1m to several metres in size	
	bench	narrow terrace	
Sand island	crest/top/plain	highest surface of island	supratidal
	slope	flanks of island	high tidal to supratidal
	sand flat apron	ribbon of gently inclined/flat sand deposit circumferential to island	
	sand cliff	small cliff usually 2m cut into sand at margin of island	
	creek/gutter	erosional incisions cut into islands	
Spit	spit crest	highest line or surface of a spit	high intertidal-supratidal
	spit swale	trough between 2 successive spits	
	spit slope	flank of a spit	
	spit lobe	accretionary lobate promontory	
Tidal creek	channel	relatively narrow erosional incision	intertidal to subtidal
	bank	steep-walled margin of creek	intertidal
	levees	linear, low mound-like sediment deposit bordering the margin of creeks	
	shoal	mid-channel mound-like sediment deposits	intertidal to subtidal
	mouth fan	fan-shaped accumulation of sediment at mouth of creek	intertidal (to subtidal)
	point bar	lensoid sediment accumulation on convex meander of creek	
Tidal flat	low tidal sand to muddy sand flat	flat surface underlain by sand or muddy sand	low tidal
	low-mid tidal mud flat	flat, smooth surface underlain by mud	low-mid tidal
	gravel flat	flat surface underlain by gravel	low tidal, varying to high tidal
	salt flat	flat smooth salt-encrusted surface	high tidal
	mangal flat	flat to gently inclined burrow-mounded surface vegetated by mangroves, underlain by mud, sand or muddy sand	mid to high tidal
	shoal	hummocky mound of sand	low tidal
	slope	gently inclined slope underlain by mud	mid-low tidal
	cliff	vertical/steep surface usually 2m high	usually at LWN and HWN level
	shell pavement	flat surface underlain by shell	low tidal, varying to high tidal

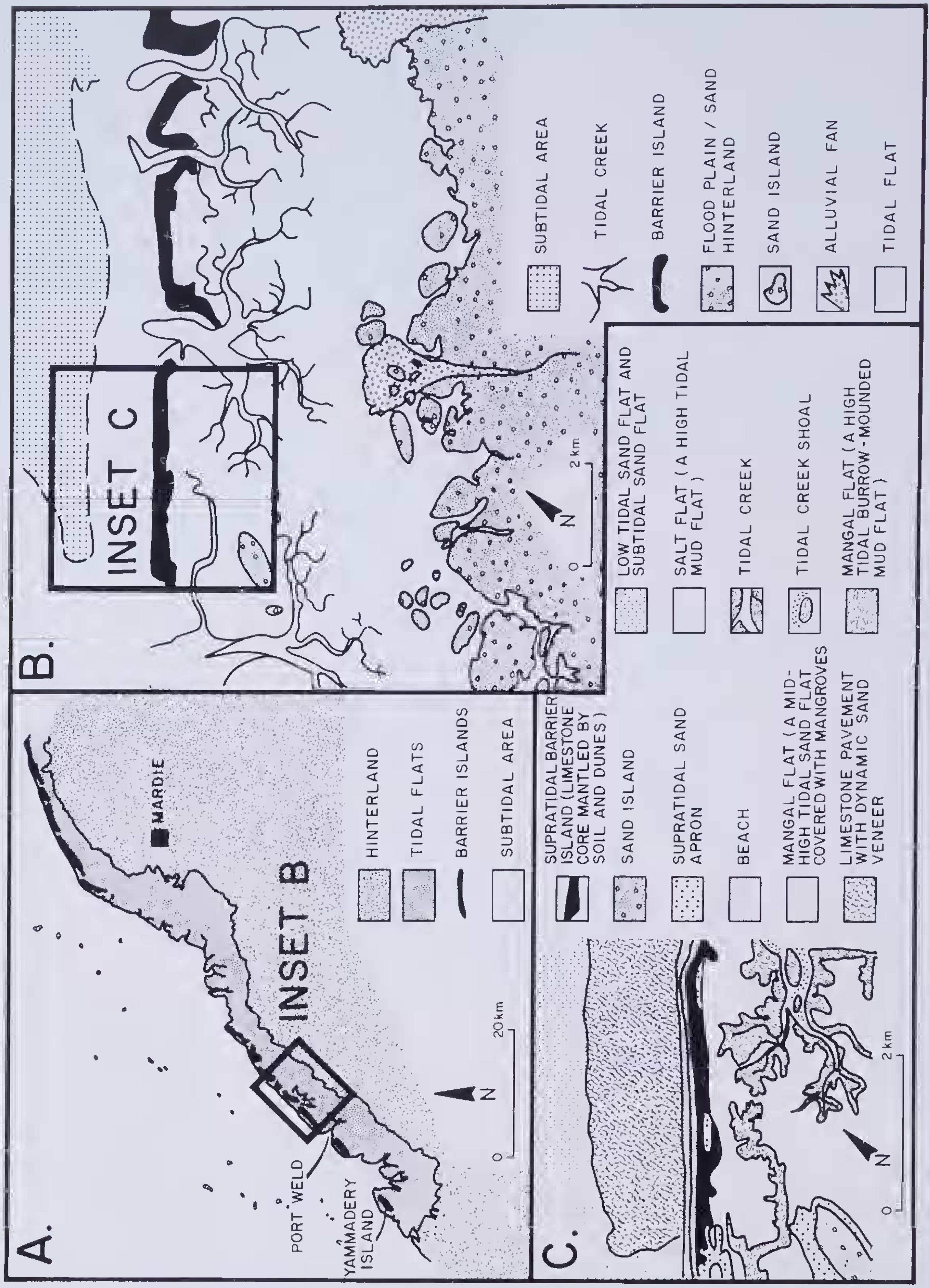

Figure 4.—Geomorphic units evident along a barrier island coast near Onslow.
A. At regional scale. B. At large scale. C. At medium scale.

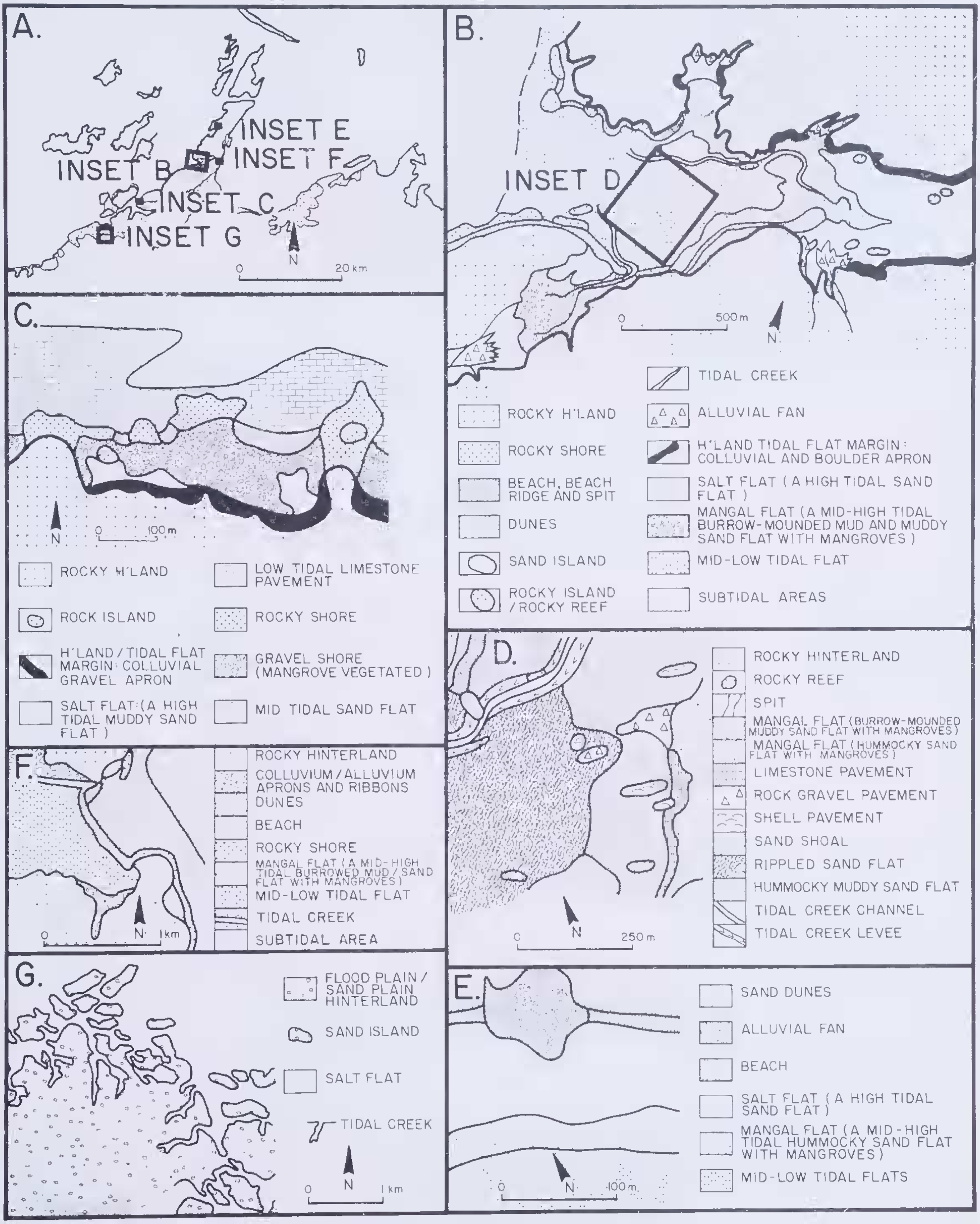

Figure 5.—Geomorphic units evident along an archipelago-ria coast, Dampier Archipelago.
A. Regional scale. B and G. Medium scale. C, D, E and F. Small scale.

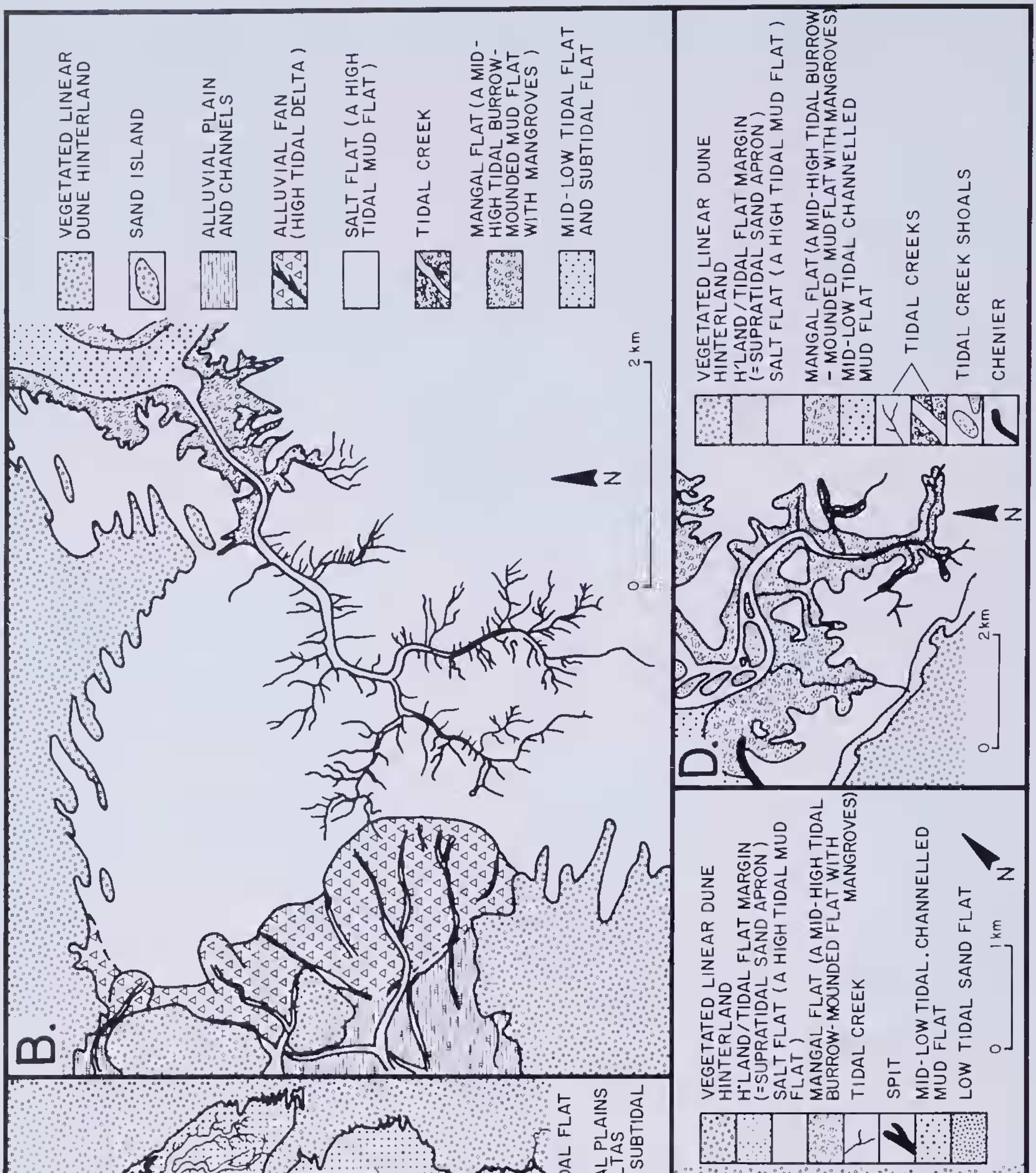

Figure 6.—Geomorphic units evident along a gulf, King Sound.
A. Regional scale. A broad tidal embayment is outlined as inset B.
B. Large scale.
C and D. Medium scale.

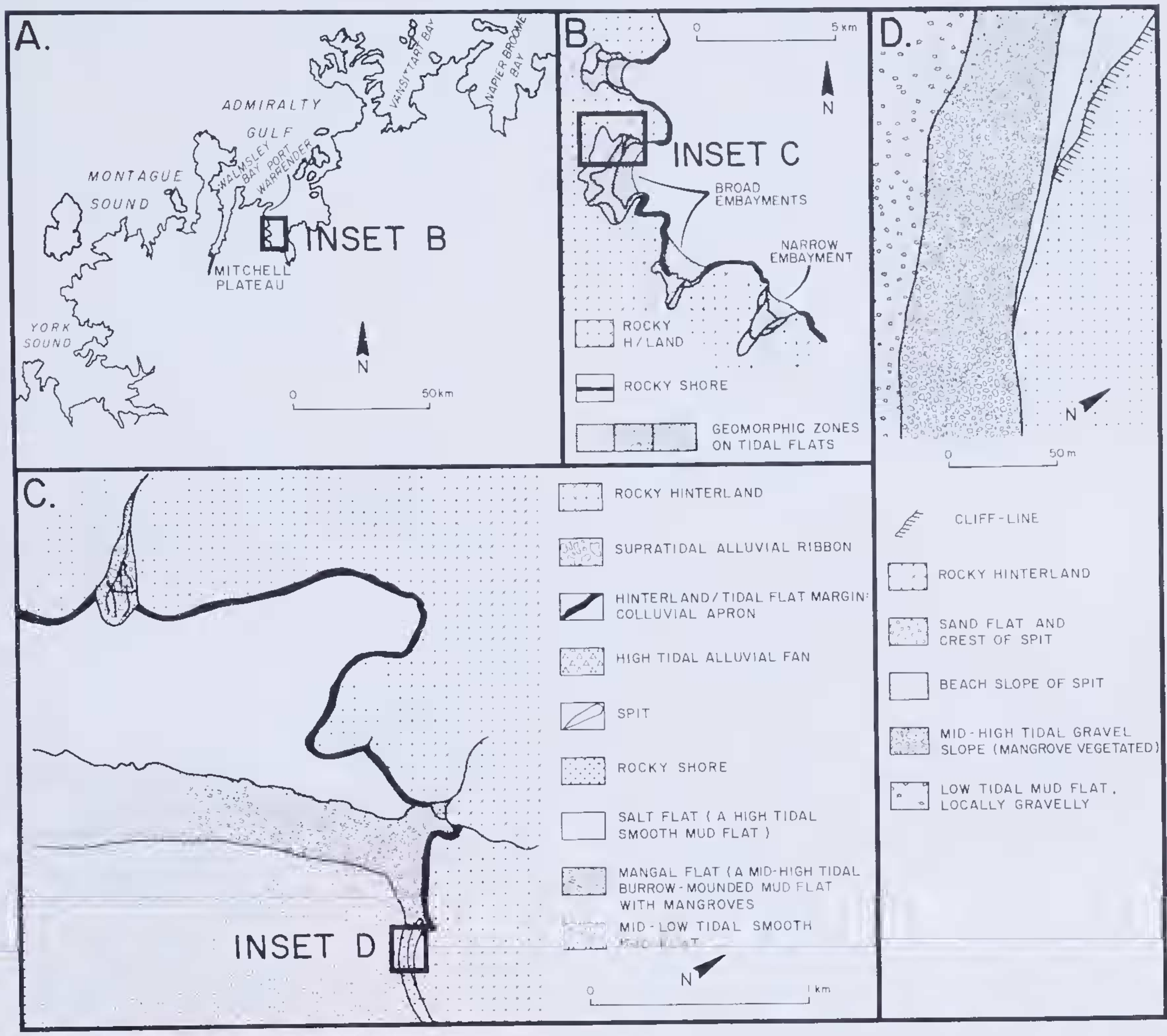

Figure 7.—Geomorphic units evident along a ria coast, Port Warrender, Kimberley area.
A. Regional scale. B. Large scale. C. Medium scale. D. Small scale.

Small scale geomorphic units

This list is quite large because many of the medium scale geomorphic units can be satisfactorily subdivided on slope, geometry, small-scale and fine-scale morphology of the substrate surface. Some examples are illustrated in Figs 11-13 and some are listed below, but a more comprehensive listing is provided in Table 5 along with definitions.

Tidal flats as medium-scale geomorphic units may be subdivided into small-scale geomorphic units on criteria of slope, substrate type and fine-scale surface features (Figs 5D & 14). Some examples using tidal flat surfaces are:

- Gravel flat
- Mangal flat (=burrow-mounded mud flat that is mangrove vegetated)
- Inclined mud slope
- Salt flat (=smooth, salt-encrusted mud flat)
- Sand flat
- Sand shoals
- Shell pavement
- Small cliff
- Smooth mud flat

Tidal creeks tend to be internally heterogeneous and may be subdivided into:

- Creek bank
- Creek channel
- Creek levee
- Creek mouth fan
- Creek point bar
- Creek shoal

Dunes, foredunes, and beach ridges may be subdivided into:

- Crest
- Hummock
- Slope (or flank)
- Swale

Fine scale geomorphic units

This list also is large because a variety of physical, chemical and biological processes interact with small scale geomorphic surfaces to develop a profusion of products. Some examples are illustrated in Figs. 11-13 and some are listed as follows:

Burrow mounds (on sand, or mud); see Fig. 11C
Burrow scours (on muddy sand); see Fig. 11F
Desiccation cracks (on mud); see Fig. 11A, 11B
Erosional rills (on sand, or limestone)
Honeycomb surface (on limestone)
Imbriccated gravel pavement
Platey gravel pavement
Megaripples (on sand)
Micropinnacles (on limestone)
Ripples (on sand); see Fig. 11D
Scour marks (on sand or mud); see Fig. 11A 11B
Small cliff (cut into mud flats)

Much of the variability at this scale can be related to differences in substrate and types of processes. For instance rocky shores cut into igneous rock will develop a suite of fine-scale features that are different from those

A

B

Figure 8.—Some examples of coastline evident at regional scale.

A. Tidal embayment (Roebuck Plains/Roebuck Bay).

B. Beach/dune shore (near Onslow).

C Barrier island complex near Port Weld showing (1) limestone barrier island which is bordered to seaward by (2) mangal flat and (3) low tidal limestone pavement and sand flat; the barrier island protects a tidal embayment within which are evident salt flats and (5) (mangrove-lined) tidal creeks.

formed where rocky shores are developed on shale or quartzite (Davies 1980). As a result a separate list of fine-scale rocky shore morphologic features could be compiled virtually for every unique geological-lithological system that is set in the various oceanographic, chemical and biological settings. Fine-scale morphologic features on sedimentary surfaces present yet another problem in variability. While there may be a greater tendency for sedimentary surfaces to portray a recurring pattern of limited number of bedforms (e.g. ripples are ripples regardless of whether they are developed on fine calcareous sand, medium siliceous sand or coarse lithoclastic sand along the Pilbara, Canning Basin or the Kimberley coastlines), there is the factor of dynamics and temporal variation. Yesterday's plane sand flat may, through spring tide action or storm activity, become today's rippled shoal.

Compiling a list of fine-scale features would not be useful and relevant at this stage. The list would be very incomplete, and it probably would be best left to individual workers to identify the various fine scale features of a shoreline at their particular study sites.

Use of tidal terms

It should be noted that tidal level is not considered a primary criterion in distiguishing small-scale geomorphic units. Nonetheless it may be used to locate particular portions of a tidal geomorphic unit relative to MSL. Consider smooth mud flats for example (Fig. 14). Smooth mud flats occur either above high water spring tide as firm, salt-encrusted, desiccated surfaces (= a salt flat), or at about low water neap tide; the latter is burrow-pocked and thixotropic. It seems preferable to distinguish between the two by referring to their tidal level or to some other conspicuous feature (such as salt encrustations, or burrows) rather than setting out a string of adjectival descriptors as a prefix viz. smooth, desiccated, salt-encrusted mud flat. Thus two mud flat types may be distinguished by their relationship to tidal level, e.g. high tidal mud flats (or salt flat), and low tidal mud flats.

It is suggested therefore that in instances where a medium- or large-scale tidal geomorphic unit can be subdivided on the basis of small-scale and fine-scale features but where the adjectival prefixes become too cumbersome, the small-scale subdivisions should be indentified by tidal level. Even if a small-scale geomorphic unit is distinct in terms of its nomenclature (e.g. gravel flat) and would not be confused with similar adjoining units, then a tidal level description could still be used at least to locate the unit relative to MSL. The tidal level description however *is not* a morphologic feature nor a geomorphic subdivision, but merely identifies where a particular geomorphic unit is occurring.

In some cases distinctive geomorphic units with distinctive small- and medium-scale features occur in a wide variety of geographic localities and recur in a specific pattern relative to MSL. Salt-encrusted, smooth mud flats occurring above levels of mean high water spring tide and burrow-mounded, mangrove-vegetated mud flats occurring between mean sealevel and mean high water spring tide exemplify this. Since these are inherently distinct units, they may be distinguished by their conspicuous features and termed "salt flat" and "mangal flat", respectively. However, some workers may prefer to use high tidal, smooth mud flat and mid tidal, burrow-mounded mud flat, respectively, for these units.

Figure 9.—Some examples of an archipelago-ria shore.

A. Large-scale features showing broad embayments, with marginal tidal flats, and straits/channels; width of view in background is 10km. Dampier Archipelago.

B. Geomorphic units evident in a broad embayment at the medium scale: (1) subtidal zone, (2) low-mid tidal flat, (3) mangal flat, (4) salt flat, (5) spits, and (6) tidal creek. Width of view is 1km. Port Warrender.

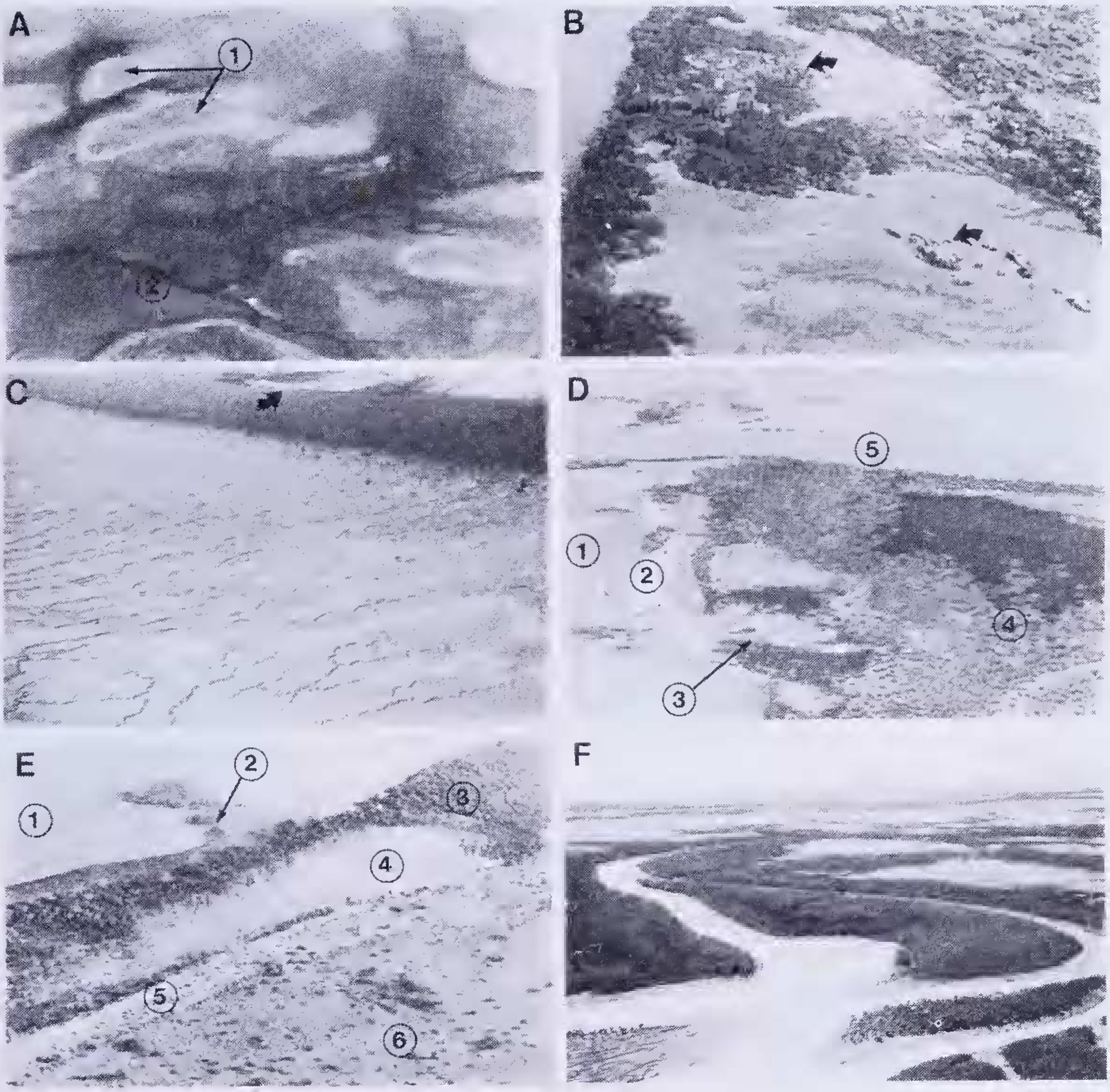

Figure 10.—Examples of geomorphic units evident at medium scale in a variety of coastal settings.

A. (1) sand islands and (2) tidal creeks surrounded by salt flat near Onslow; width of view 2km.

B. Rock islands (arrowed), protruding through salt flat, Mitchell River estuary, Kimberley.

C. Channelled low-mid tidal mud slope succeeded to landward by mangal flat, chenier (arrowed) and salt flat, King Sound. Width of view is approximately 1km.

D. Coast showing (1) barrier island, (2) beach ribbon, (3) alluvial fan, (4) mangal flat, and (5) riverine channel; Fortescue River. Width of view is approximately 1km.

E. Coast showing (1) low tidal sand flats, (2) limestone pavement, (3) mangal flat, (4) high tidal sand flat, (5) beach, and (6) supratidal barrier island; near Onslow. Width of view is approximately 1km.

F. Tidal creek showing steep creek banks and mangrove-vegetated mid-creek shoals. King Sound. Width of view is 3km.

Geomorphic Units and Habitats

The term "habitat" refers to space in which abiotic factors determine as suitable for colonisation by biota, and a geomorphic approach in describing habitats merely identifies many of the major attributes of an environment that are critical to maintaining or eliminating elements of the biota. For example, landform and substrate may control the variability, stability or dynamism of a shoreline; the type of substrate may have its effect on biota through mobility, permeability, transmissivity, nutrient/food retention, oxygenation, etc. A system of geomorphic units therefore forms a logical framework for the delineation/identification of habitats.

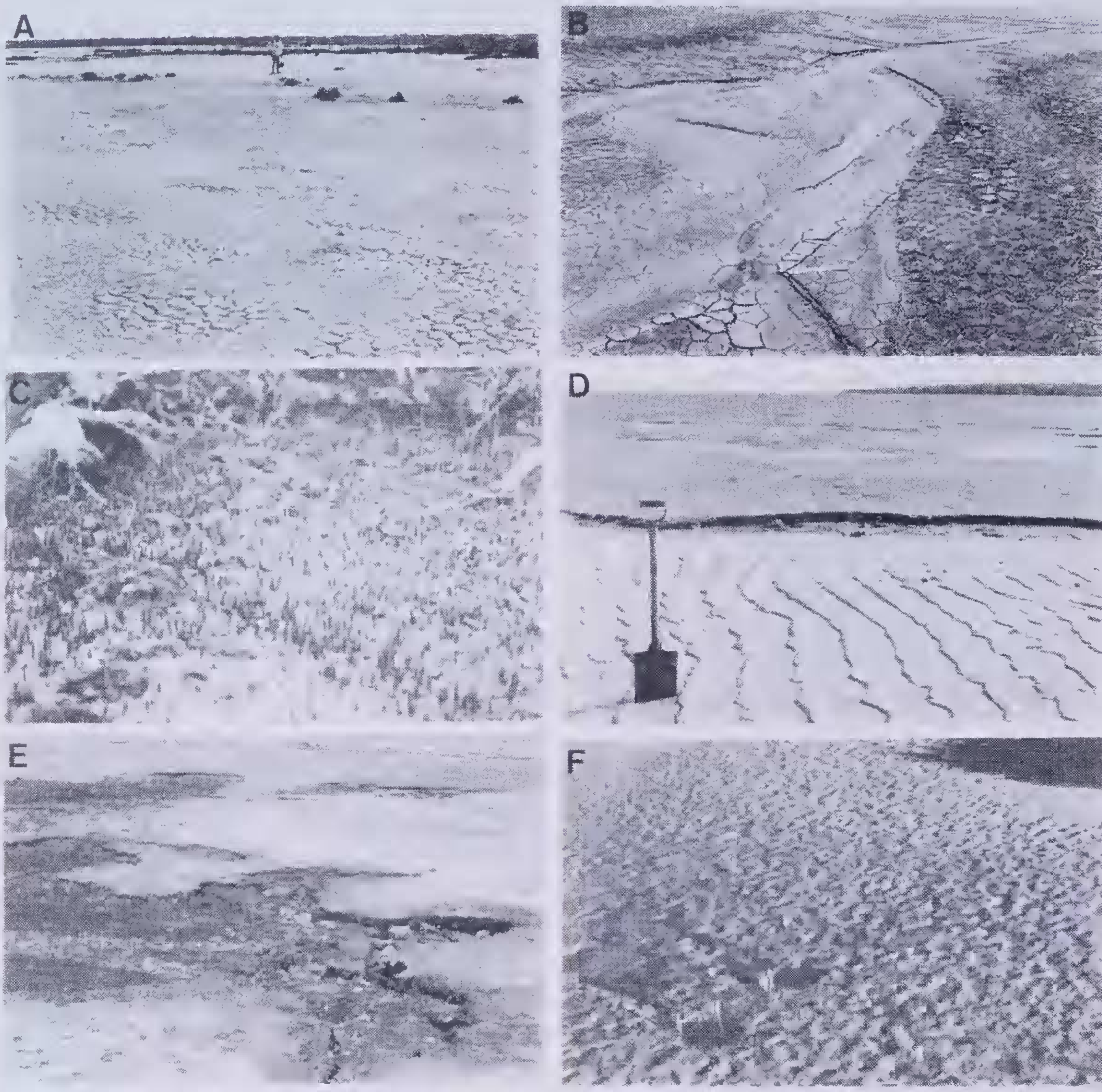

Figure 11. Examples of fine-scale geomorphic units.

A. Scoured, smooth mud flat surface with desiccation polygons on a salt flat, King Sound.
B. Variety of geomorphic features in a small tidal creek cut into a salt flat, King Sound. Scale is 30cm long.
C. Hummocky, burrow-mounded surface on a mangal flat, Dampier Archipelago. Width of view is 1m.
D. Smooth, burrow-pocked mud flat separated by small cliff from a rippled sand ribbon, King Sound.
E. Small cliff, 20cm high, and breccia deposit, cut into salt flat, Dampier Archipelago. Hammer for scale.
F. Hummocky, low-tidal, muddy sand flat, Dampier Archipelago. Width of foreground is 10m.

Several authors have already utilised a geomorphic framework as a basis for identification of habitats (Thom 1967, Phleger 1977, Semeniuk *et al.* 1982). Also, in many biological treatises, the notion of "habitat" is rooted deeply in, or overlaps with, geomorphic concepts (eg. Eltringham 1971, Yonge 1966, Odum 1971) and essentially these works implicitly identify the obvious (geo)morphology of an area and term such features habitats. This is not surprising considering that benthic organisms interact intimately with the shape, type and dynamics of the substrate.

In this paper at each scale of reference listed above, the term geomorphic unit in practical terms is interchangeable with the term "habitat" when a particular landform type is identified. For instance,

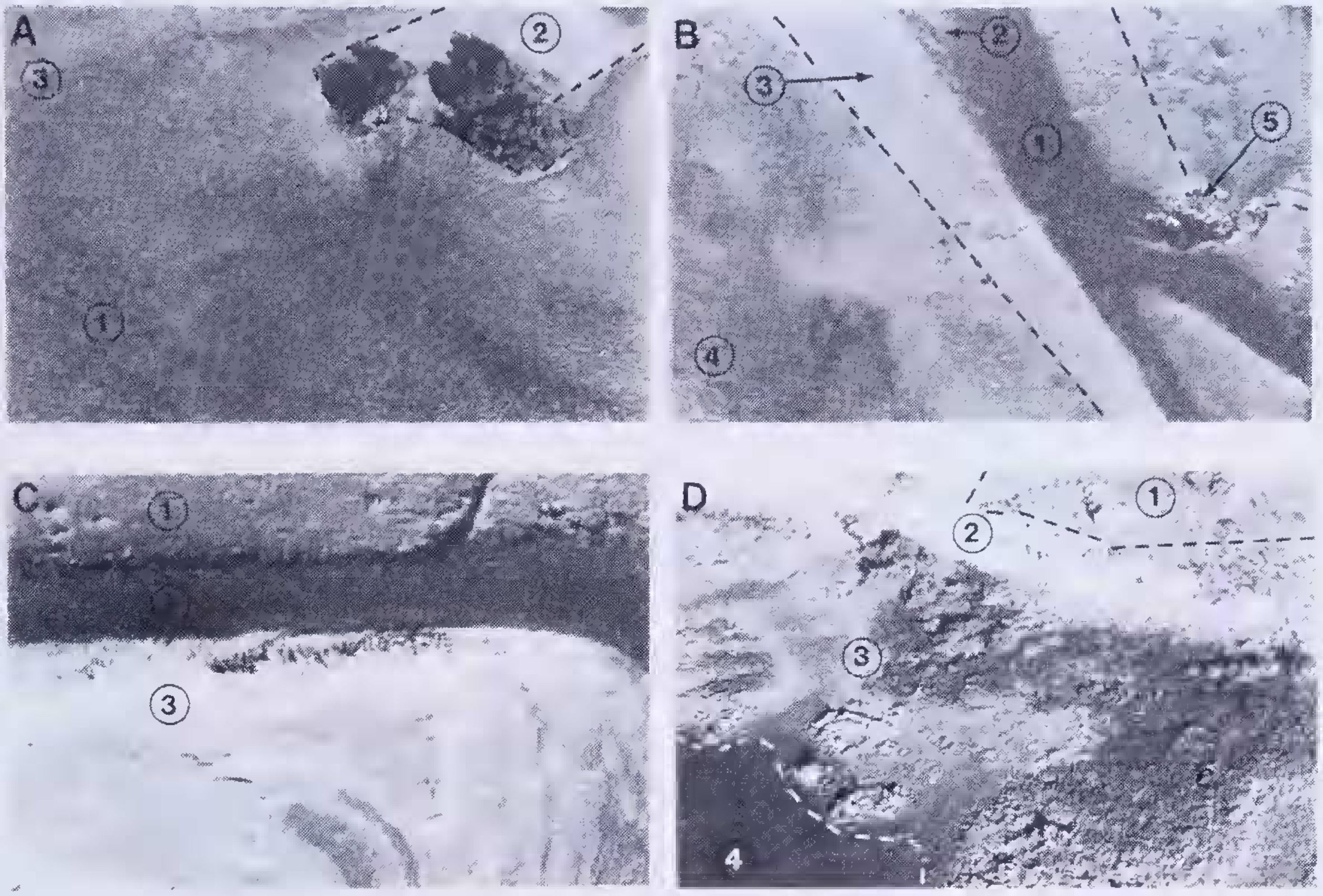

Figure 12. Examples of juxtaposition of small-scale geomorphic units evident in vertical aerial photographs in Dampier Archipelago. Fine-scale variation between units is also evident in some photographs.

A. (1) Hummocky, low-tidal, muddy sand flat, (2) sand shoal locally vegetated by mangroves, and (3) tidal creek. Width of view is 100m.

B. Tidal creek with components of (1) channel, (2) shoals, (3) levees; the creek traverses a hummocky, low-tidal, muddy sand flat, (4) and locally a rocky reef, (5) protudes. Width of view is 100m.

C. Low-tidal zone within which is evident (1) smooth muddy sand flat, (2) a tidal creek and (3) a smooth sand shoal. Width of view is 100m.

D. Rocky hinterland (1), bordered by a beach ribbon of sand (2), and an inclined rocky shore (3) within which are evident various fine- scale variations, the low tidal flats are noted as (4). Width of view is 100m.

rocky shores may be mapped as a regional- to medium-scale geomorphic unit and at these scales, rocky shores also may be viewed as a particular habitat for a range of organisms. Thus habitats may be viewed in a decreasing scale similar to geomorphic units, until at the smallest scale the biologist deals with "microhabitat" which is perhaps equivalent to, but may be smaller than the fine-scale geomorphic unit. To illustrate this principle consider again the rocky shores (Fig. 13). At the small scale this habitat type may comprise cliff shores, bouldery shores, sloping shores, pocket beaches, in which various tidal levels can be recognised as subdivisions of the rocky shore. At still finer scales exposed shear surfaces, notches, gravel accumulations, fissures and benches provide even smaller scales of reference for habitats.

The only complication in relating habitats to geomorphic units is that at some stage similar geomorphic units may be exposed to differing physico-chemical conditions and so would be different habitats. Rocky shores inundated by hypersaline water are a different habitat to those inundated by oceanic or brackish water. However, other factors being equal, purely on surface forms and features, geomorphic units may be equated with habitat units as long as the scale of reference is nominated.

Discussion

The results of this review and the proposed classification are directly applicable to the coast of tropical Western Australia since the philosophy was mainly developed on a data base from that region. However, the same approach, if not the detailed terminology, can be applied to other marine environments and other tracts of coast along Western Australia. For instance the deeper water subtidal shelf environments of tropical northwestern Australia, and the coastal region of southwestern Australia where the present Quindalup and Spearwood dune systems form continuous shoreline belts may be similarly classified utilising the approach presented here.

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Figure 13. Variability at the small and fine scale along 2 shoreline types. A, B and C are rocky shores along the Dampier Archipelago. D, E and F are limestone barrier-island shores between Port Hedland and Onslow.

A. Rocky shore showing cliff headlands alternating with bouldery shores. Field of view in foreground is 5m wide.

B. Rocky shore composed of sheer cliffs, fissured cliffs and boulders. Field of view is 3m wide.

C. Rocky shore composed of fissured slopes inclined towards right, alternating with steep/vertical fissured cliffs. Person (arrowed) for scale.

D. Low tidal limestone pavement shore showing broad microscale hummocks and local areas of microscale pinnacles in centre of field. Trees for scale are 2m high.

E. Limestone shore at mid-tidal zone showing pinnacles developed on top of an elongate reef. Field of view is approximately 10m wide.

F. Limestone shore at high-tidal level showing 5m high cliff with pinnacles and boulders developed on surface. Person for scale.

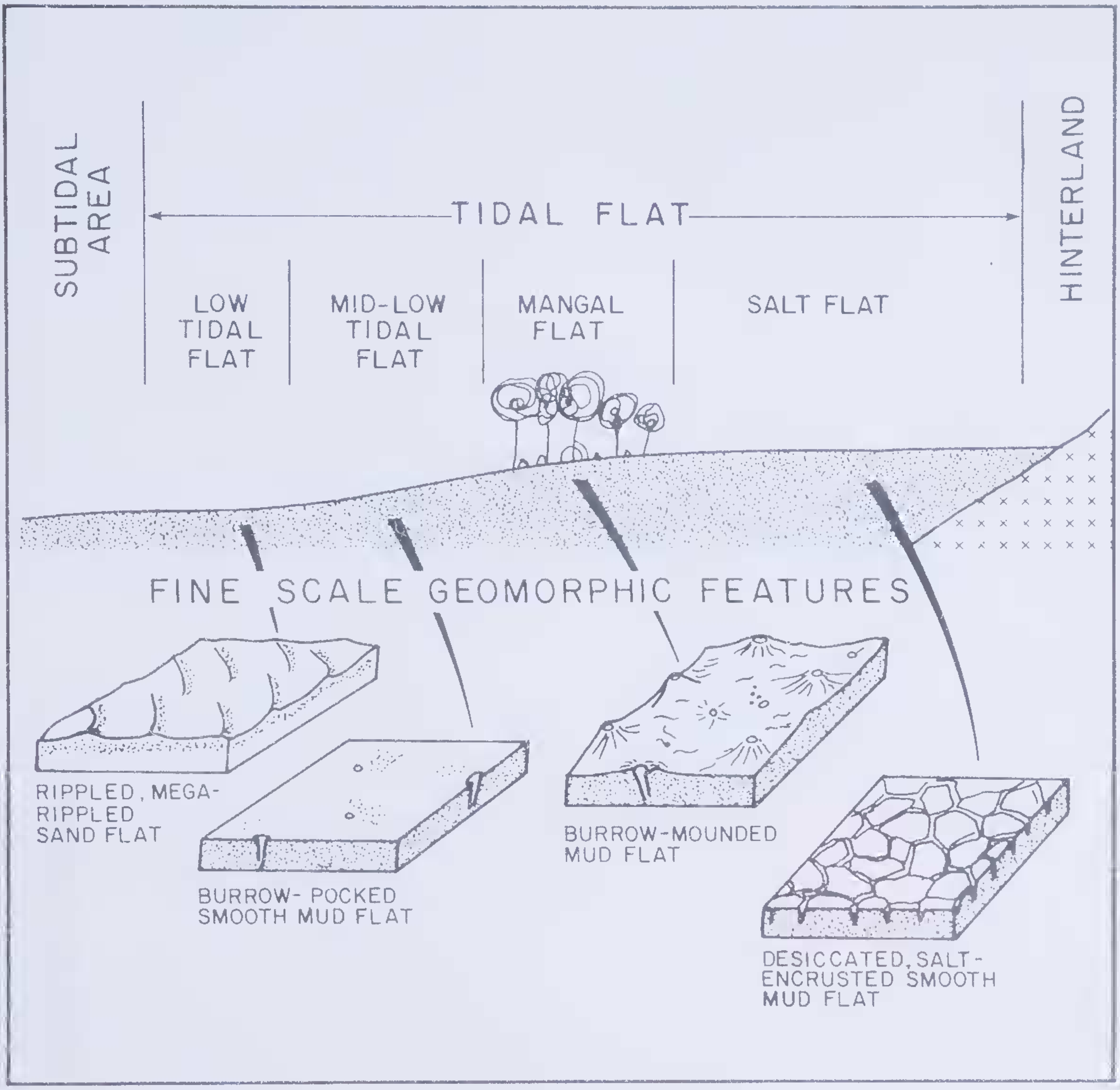

Figure 14. Typical geomorphic subdivisions of a tidal flat showing their fine-scale geomorphic features.

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